A hybrid radio propagation channel model for realistic confined environments

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Abstract

Radio communications often take place in confined environments like city areas. The propagation channel presents shadowing and multipath phenomena due to interactions between radio wave and environment. In this work, a general hybrid channel model concept is proposed to associate the advantages of existing deterministic and statistical models. One of the model applications is introduced using a geosynchronous satellite as transmitter and a land mobile as receiver.

1. Introduction

The propagation channel is the support of all wireless communications between single or multiple transmitters and receivers. It consists of environments in which radio waves propagate. Combining with antennas, a wireless transmission channel can be defined which allows information to be send through radio links in a point-to-point or point-to-zone manner. It is therefore the key element in wireless communication system design.

In order to understand channel behaviors in different propagation conditions, the propagation channel models are among the most useful solutions. They are developed to accompany or even to replace measuring campaigns which turn out to be expensive and intricate. Being easy to set up, these models rely heavily on simplification privileging either computation speed or accuracy. Four main families exist in channel modeling: rigorous models, deterministic models, statistical models and hybrid models. However, rigorous models are seldom considered in satellite communications as a prohibitive amount of calculation is needed. Our work belongs to the last family which combines the advantages of the deterministic models and statistical models.

In particular, a deterministic module based on ray-tracing (Ergospace software) is used. This simulation software has been validated in collaboration with CNES. In addition, a statistical module takes into account statistical laws which describe the signal's behaviors according to different receiving states, similarly to existing works, for example, [1] and [2].

The paper is organized in the following way: section 2 describes the statistical channel behavior based on analyze of simulated signals. The concept of our hybrid model is presented in section 3. The model performance is evaluated in section 4, followed by conclusions given in section 5.

2. Channel behavior analyze

In this paper, we are presenting a possible application of our hybrid model in Land Mobile Satellite (LMS) channels to demonstrate the modeling concept.

The signal is simulated by Ergospace software based on which the channel behavior is studied. The simulations are configured with a geosynchronous satellite working at 1500 MHz (*L* band) and a land mobile receiver traveling through confined environments. Figure 1(a) and Figure 1(b) show the signal and it's cumulative density function, respectively.

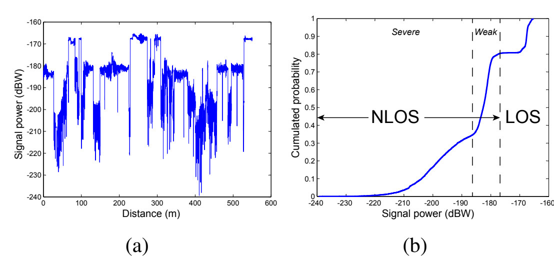

Figure 1. CDF (b) of simulated signal (a) in built-up urban environment of Toulouse

It can be observed that the signal exhibits three receiving states: LOS (*line-of-sight*), NLOS (*non-line-of-sight*) severe and NLOS weak. The LOS areas can be identified from the high and nearly stable signal level, which results in a concentration of values on the right tail of the cumulative density function; the NLOS weak areas are characterized by a relatively low signal level with more fluctuations; the NLOS severe areas spread a lot more on the left tail because the received signal fluctuations are high.

In realistic simulations, the occurrence rate and the change rate of these three states are random. In the work of Fontan [1], a three-state Markov chain determines the state probabilities and state transition probabilities. We've proposed a novel approach [3] to identify these states using the deterministic module.

This approach, called Σ_{CI} segmentation, takes into account the *combination of interactions* (CI). For a given path, the radio waves may undergo a certain number of reflections (p) and diffractions (q) before arriving at the receiver. This path is noted pRqD. It has to be pointed out that, in satellite communications, the maximum number to be taken into account is 2 for reflection and 1 for diffraction. Otherwise the signal is too attenuated and can be excluded. Six types of CI can thus be considered. Also, in order to distinguish paths by their significance, we give each type of CI a numeric weight. The less a path is attenuated, the greater a value it gets, as show in Table 1:

CI	0R0D	1R0D	2R0D	0R1D	1R1D	2R1D
Weight	32	16	8	4	2	1

Table 1. Types of CI and associated weights

Therefore, each sample point can bear a sum (noted Σ_{CI}) if we add up these weights by CI type, not considering the number of paths belonging to the same type. For example, if three CI types, 0R0D, 1R0D and 2R1D, arrive at a sample point, the associated $\Sigma_{\mathrm{CI}} = 32+16+1 = 49$ and indicates the receiving condition of this point. The fact that binary numbers are chosen makes the correspondence unique between Σ_{CI} value and CI types. The possible values of Σ_{CI} range from 1 to 63.

As each sample point is associated with a Σ_{CI} value, if we sort the Σ_{CI} evolution from 1 to 63 and reorganize the signal sample points according to the sort, same receiving conditions are regrouped together, making it easier to segment the signal, as shown in Figure 2.

Therefore, the LOS and NLOS areas can be separated at the point where $\Sigma_{\mathrm{CI}} = 32$ because this indicates the presence of a direct path. As for NLOS severe and weak areas, we have shown they can be identified according to the presence of simple reflected path (1R0D) because it's second least attenuated path after the direct path.

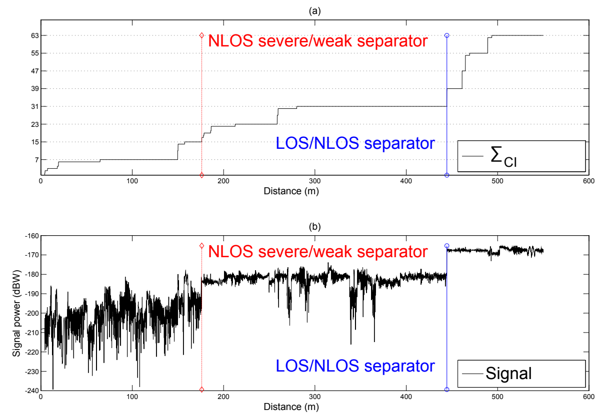

Figure 2. (a) Sorted Σ_{CI} evolution; (b) Associated signal along the sort

Hence, it becomes possible to regroup and extract all LOS signal parts to analyze. We have found that the signal in LOS areas is in general stationary. This can be explained in the following manner: the signal attenuation mainly depends on the direct pathloss, the latter being signal's free space pathloss. We know that this loss is relative to the distance d between the transmitter and the receiver. However, the distance between the Earth and a satellite is so great (about 36000 kilometres) that receiver courses, often being several kilometres, do not change d in a significant way. Therefore, the direct pathloss is nearly constant. What's more, this implies that the signal's local mean is nearly invariant and facilitate the separation of slow and fast-fading.

Using the sliding-window technique [4] with a window length of 48λ, we can subtract the local mean from the signal and extract the fast-fading as in Figure 3:

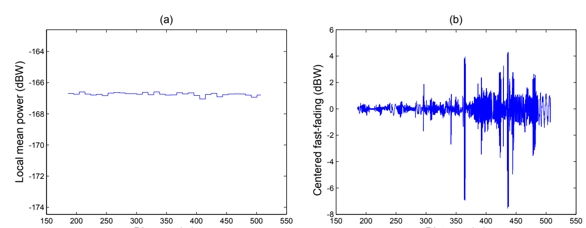

Figure 3. Signal local mean evolution (a) and extracted fast-fading (b)

Figure 3(a) confirms the quasi-constant signal local mean. We propose therefore a constant global mean $\overline{A}$ in LOS areas. On the other hand, we need to find a statistical model for the fast-fading as in Figure 3(b). This refers to a procedure called *law recognition* of which the details are described in [5]. In the context of satellite communications, the Nakagami-m model [6] turned out to be the most adequate and robust. So the statistical parameters for LOS areas are: constant global mean $\overline{A}$, m et Ω of Nakagami-m model.

The same study has been carried out for NLOS areas but the result is quite different. In fact, the signal's stationarity is very limited, which implies it can be intricate to separate the slow and fast-fading using the sliding-window technique. We propose another model, the lognormal model, which is general as it takes into account the slow and fast-fading together. Two sets of parameters are estimated for NLOS severe (μ_s and σ_s) and weak (μ_w and σ_w) with μ and σ being the signal's global mean level and standard deviation.

3. Proposed hybrid model

In the previous section, the channel behavior has been analyzed based on simulated signals. It has been shown that different statistical models, each with adequate parameters, can be applied according to the receiving state. However, as all statistical modeling, the main challenge lies in choosing the adequate parameters, as they influence directly the model's quality. In fact, our hybrid model should takes as input the deterministic data which influence the channel's statistical behaviors, and outputs the suitable statistical parameters.

The main deterministic data are transmitter's position and terrain type. Due to the length limit of this article, the result of the following case is presented: we use a geosynchronous satellite transmitter with a longitude of 300° and only built-up urban areas are considered. In fact, detailed studies have been carried out for 13 satellite positions and 3 terrain types [7].

Hence, if two environments A and B are of the same type, the statistical parameters estimated for A (with the same transmitter position) can be directly reusable for the simulation in B without the need of launching full deterministic simulations in B. In fact, giving a receiver course, it is only necessary to use Ergospace software to detect the sample points of the three receiving states. Then, we consider the respective statistical parameters for A and feed them into random generators to simulate the received signal. Finally, the generated samples are associated with sample points according to the receiving state and the hybrid simulation is complete.

4. Model performance evaluation

We've chosen to built-up areas of Toulouse city, "Toulouse Carmes" (Figure 4) being environment A and "Toulouse Capitole" (Figure 5) being environment B.

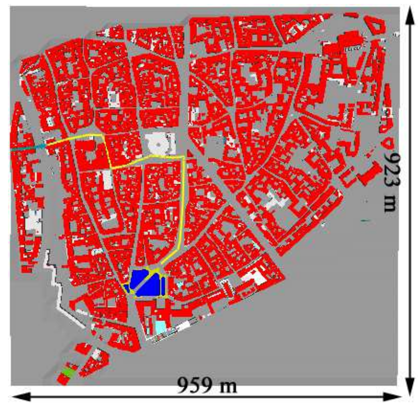

Figure 4. Built-up environment named "Carmes" and receiver course marked in yellow

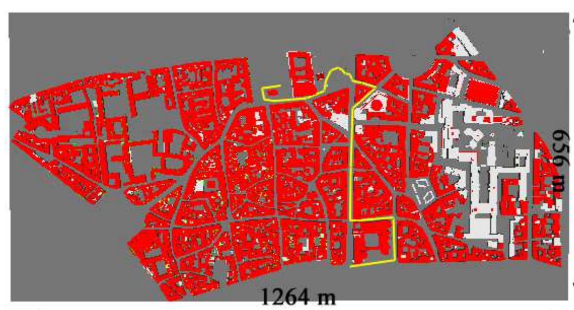

Figure 5. Built-up environment named "Capitole" and receiver course marked in yellow

With the simulated signal along the receiver course in Figure 4, we've obtained the followed statistical parameters listed in Table 2:

LOS			NLOS weak		NLOS severe	
m	Ω	$\overline{A}$	μ_w	σ_w	μ_s	σ_s
0,69	2,68	-171,6	-181,2	5,7	-195,4	9,1

Table 2. Three-state Parameters estimated for "Carmes"

For the simulation in "Capitole", the deterministic module detects the location of the three states and the signal is simulated respectively using Table 2.

4.1. Accuracy evaluation

The accuracy of simulation can be evaluated by comparing cumulative density functions. The *hybrid signal* produced by our model is compared to the *deterministic signal* which is the result of a full deterministic simulation by Ergospace as shown in Figure 6.

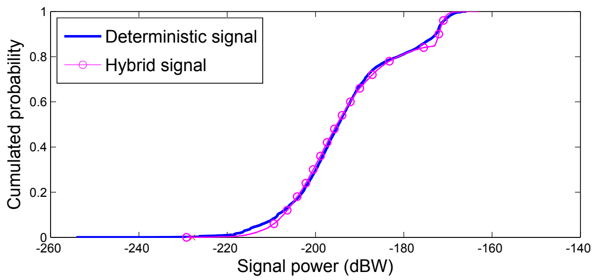

Figure 6. Comparison of unsupervised hybrid signal to deterministic signal and supervised signal

The figure shows the signal simulated by our hybrid model is very closed to the deterministic signal, which means the three-state hybrid model leads to accurate and satisfying simulation results.

4.2. Computation time evaluation

Our model's performance in terms of computation time is estimated by comparing its complexity an existing model, which is Ergospace's full deterministic simulation. As mentioned before, the Ergospace software is configured to allow two reflections and one diffraction. In raytracing methods, the number of interactions greatly influences the model's complexity, which is why they are time consuming. For example, Ergospace uses 275 seconds to simulate a course of about 7000 samples, using an Intel Pentium 4 Processor of 3 GHz.

The hybrid model consists of two parts: the statistical model is very fast thanks to random generators which take only 2.5 milliseconds to simulate 7000 samples. On the other hand, the deterministic model is also optimized because it is only launched to determine the location of the three states. In other words, we can configure Ergospace to allow a maximum of one reflection, as only the existence of 0R0D or 1R0D needs to be detected. This dramatically reduces the computation time. In total, a gain of about 10000 times can be considered in comparison to a purely deterministic model.

5. Conclusion

We have presented in this paper a novel hybrid channel model. Different receiving states can be detected by a deterministic model while each state is analyzed and modeled using adequate statistical models with adapted parameters. These parameters can be directly reusable in similar environments, leading to a high-performance channel simulation. Based on an application example with geosynchronous satellites and built-up urban areas, our model has been compared to existing models in terms of simulation accuracy and computation time.

Although the work is based on LMS channels, the model concept is independent and can be easily generalized to other situations. As long as multipath phenomenon exists, it is possible to set up similar studies to implement an appropriate hybrid model.

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